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Comparative Analysis of Mineralogical Characteristics of Clay-Rich Soil Samples obtained from Gbajimba, Angbaaye and Makurdi Areas of Benue State

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ABSTRACT
The elemental concentrations and mineralogical composition of soil samples from Gbajimba, Angbaaye and Makurdi areas of Benue state were evaluated. Their clay fractions (particles smaller than 2 microns) studied through a series of mineralogical, chemical and physico-chemical analyses showed that the colour test of the sample showed brown to red. The study suggested that morphology of kaolinitic and quartz minerals is influenced by the parent material (i.e. feldspars or micas) and degree of chemical weathering. The pH values of pore water from clay samples showed acidity, ranging from 4.93 - 6.96. The electrical conductivities (EC) of the samples ranged from 2.68-3.48 mS/cm – 3.48mS/cm. The CEC results of the sample showed a 6.98-7.32 range. The results of X-ray diffraction (XRD), infrared spectroscopy (IR), Scanning Electron Microscopy (SEM) characterization showed that the soil samples from these three areas with clay-rich soil were a mixtures of kaolinite, quartz, muscovite, microline, pyrite, chlorite and sylvite, showing quartz present in all samples. The results obtained from XRF showed that the clay samples mostly composed of silicon (IV) oxide in Gbajimba(51.538%), Angbaaye (49.107%) and Makurdi (64.826%); Aluminum in Gbajimba (18.883%), Angbaaye (22.419%) and Makurdi(16.319%);Iron in Gbajimba (8.3230%), Angbaaye (8.8611%) and Makurdi (4.2672%); Manganese, phosphorous, titanium etc. These are the proportion of the major expected elements. Hence, the results from the analysis fell within the same range of results from other works studied.

Keywords: Aluminum, Bricks, Kaolinite, Makurdi, Quartz

INTRODUCTION
Clay minerals are the most important industrial minerals. Millions of tons are utilized yearly in various applications. These applications include uses in geology, the process industries, agriculture, environmental remediation and construction. The reason for utilization of certain clay minerals in specific application is that the physical and chemical properties of a particular clay mineral are dependent on its structure and composition (Fatai *et al.*, 2014).

In recent years, many laboratories around the world were interested by the study of clays. This interest is justified by their abundance in nature (covering about 42% of the earth's crust), the importance of the specific surface areas developed, the presence of electric charges on the surface and above the exchangeability of interlayer cations. The latter one, also known as compensating cations, is the main element responsible for the hydration, swelling and plasticity, (Hattab and Chlendi, 2013). Although clay usually contains phyllosilicates, it may contain other materials that could impart plasticity when wet and also harden when fired. However, associated phases in clay may include organic matter and materials that do not impart plasticity, (Bakker, 1993). Clay minerals share a basic set of structural and chemical characteristic and yet each clay mineral has its own unique set of properties that determine how it will interact with other chemical species. The variation in both chemistry and structure, among the clays lead to their applications in diverse fields (El Kasmi *et al.*, 2016).

The physical and chemical properties of a particular clay mineral are dependent on its structure and composition that reason for utilization of certain clay minerals in specific application (Fatai *et al.*,2014).The complex nature of clay makes its study and findings an ever fresh area of interest especially to the world of science. Clay and its mineral shave played major roles in anthropogenic activities. The low cost of clay and its relative abundance in nature, high sorptive/electric charge properties, plus ion exchange ability and compatibility with several materials, give it a wide range of application

(Barbel and Kurniawan, 2013; Costanzo, 2001). Clays are of immensed geological, industrial and agricultural importance (Melero *et al.*, 2007; Choo *et al.*, 2016 Ekosse, 1994). The mineral assemblage of clays helps in understanding and management of erosion and flood related problems (Kotoky *et al.*, 2006), and in the construction of tunnels, road cuts, fills and dams (Oden *et al.,* 2001). Depending on the physical and chemical characteristics, clays may find application in a number of industries such as plastics, paint, ceramics, ink, catalysts, pharmaceutical and fibre glass, construction, agricultural, textile, paper, electrical, nuclear energy, and petroleum industries among others (Patel *et al.,* 2006,;Obaje*et al.*, 2013). In order to determine the effects of utilizing clay on soil, it is necessary to examine the microstructural morphology, determine the chemical, mineralogical composition and analyze the various available phases in such clay deposit.

The raw materials used for brick productions are soil clay or sediments from river, which are rich in fine particles. Most of the brick kilns use Assam coal, Slack coal and/or lignite which contain high level of sulphur and high ash content (25-30%) (Bhanarkar *et al.*, 2002). About 70% of coal, 24% saw dust and remaining 6% wood and others are used as fuel by brick kilns (Joshi and Dudani, 2008). In production of generally high quality of pottery the chemical compositions of clay raw materials, mixing proportion of raw materials, particle size, glazing materials and production technology attributes (Swapna, 2013) because each industrial process requires certain property specifications that must be met by either the raw or refined clay. One of the detrimental effects of not considering these quality parameters is that since the refining or beneficiation of clays is already an expensive process and it becomes uneconomical if the composition and properties of the raw clay differs greatly from the desired specification level of sulphur dioxide and black carbon (Skinder *et al.*, 2014).

This work aims at characterizing the mineralogical and chemical parameters of clay-rich soil, thereby investigating the right quality and proportion of local clay raw materials for pottery making and other industrial applications.

MATERIALS AND METHODS

Instruments and Reagents

Potassium bromide, Potassium Chloride, Nitric acid, Sulphuric acid, Hydrogen chloride and Toluene of analytical grade were used. Also, sodium hexametaphosphate, Calcium chloride, Acetic acid, glacial acetic acid, Ammonuimacetate, Ammonium hydroxide were used without further purification. The instruments employed for this study are energy dispersive x-ray florescence spectrometer(Mini PALA4), Scanning electron microscope (Q150R), X-ray Diffraction instrument (X-SUPREME8000) and Fourier Transform Infra-Red(Agilent tech. Cary630).

Sampling and Sample Treatment

The point sampling method by Akinyemi *et al*. (2014) was used. Clay-rich soil samples were collected from the three specific regions, Gbajimba, Angbaaye and Makurdi and taken to the Department of Soil Science, University of Agriculture Makurdi, for identification. They were prepared for analyses by crushing using a jaw crusher, followed by milling to fine powder and passed through a 2 mm sieve, and a screening of gravel >2 mm in diameter. Each of the samples were labeled and stored in sealed polythene bags away from the sunlight or in UV resistant containers prior to analysis (Akinyemi *et al.*, 2014).

Physicochemical Parameters

Analyses for colour, particle size distribution, bulk density, pH and CEC were carried out on all the samples using standard laboratory procedures. Colour determination was done by visually comparing the samples with soil colours in the Munsell Soil Colour Charts to obtain the hue, value, chroma and colour of the samples (Ekosse *et al.*, 2007; Young *et al.*, 2008).

Bulk Density (g/cm^3) =

$$= \frac{Weight\ of\ oven-dry\ soil}{Volume\ of\ oven\ dry\ soil} = \frac{W_3 - W_1}{V} \quad (1)$$

The volume (V) of the core sampler was determined using (v-volume of core sample) = $\Pi r^2 h$ (Gebre, 2017).

The Air-dry moisture content was calculated using equation 2:

$$Ws = (M_{AD} - M_{OD}) / (M_{OD} - M_{tin}) \quad (2)$$

Ws = water content of air-dry soil, by weight (gg^{-1}), M_{AD} = mass of air-dry soil and tin (g), M_{OD} = mass of oven-dry soil and tin (g), and M_{tin} = Mass of tin (g).

Chemical Analysis

Chemical analysis was carried out on all three samples. Scanning Electron Microscopy (SEM) was done to determine the elemental composition and surface morphology of the clay, X-Ray Florescence (XRF) was done to determine the chemical composition of the clay while the X-Ray Diffraction (XRD) was carried out to study the clay mineralogical content. Using the Debye-Scherer's equation on the crystallographic characterization, the crystal sizes were calculated from peak positions at 2Θ and X -ray counts (intensity).

$$D = \frac{K\lambda}{\beta Cos\theta} \quad (3)$$

where D is the crystalline size, K is Scherrer constant with value 0.9, λ is the wavelength of X-ray, ß is full width at half maximum and θ is the differential angle (Itodo *et al.*, 2017) . The functional groups of clays from Gbajimba, Angbaaye and Makurdi were all obtained using Fourier Transform Infra-red (FTIR) technique.

RESULTS AND DISCUSSION

Visual inspection of samples

Apparent color of Gbajimba, Angbaaye and Makurdi samples were examined with the naked eye and were found to be of varying colours. Gbajimba sample showed a dark brown colour which could be attributed to high concentration of silicon and average concentration of Iron and Aluminum (Olusola *et al*, 2013), while that of Angbaaye and Makurdi reddish and black colour respectively**.** They were of no offensive odour and in powdery form when marshed and sieved.


(a)


(b)


(c)

Plate 1: Pictorial Representation of Clay from (a) Gbajimba (b) Angbaaye and (c) Makurdi

Physicochemical Parameters

Table 1: Physicochemical Parameters of Samples from Gbajimba, Angbaaye and Makurdi

S/N	Parameters	Gbajimba	Angbaaye	Makurdi
1	*pH*	4.93	5.01	6.09
2	*EC(µs/cm)*	2.68	3.48	2.68
3	*CEC* (NH_4OAC)	7.18	7.32	6.98
4	*BD* (gcm^{-3})	1.17	0.99	1.57

Table 2: **Particle Size Distribution of Samples from Gbajimba, Angbaaye and Makurdi**

S/N	Parameters	Gbajimba	Angbaaye	Makurdi
1	Sand (%)	42.24	50.24	58.24
2	Silt (%)	16.56	14.56	10.56
3	Clay (%)	41.20	35.20	31.20

pH:

Gbajimba, Angbaaye and Makurdi samples showed a pH of 4.93, 5.01 and 6.09, respectively. This implies that all samples showed acidity but the Gbajimba sample is in the *very strongly acidic class*, having the highest concentration of hydrogen ions. The Angbaaye sample was in the strongly *acidic class* and Makurdi sample are slightly acidic, that is they contain lesser concentration of hydrogen ions. The acidity is suspected to have resulted from hydrolysis of silicate in water giving rise to silicic acid and a base (Churchman and Lowe, 2012).

Electrical Conductivity (EC)

Conductivity is the measure of salts in soil (salinity). The results for Gbajimba - 4.63, Angbaaye - 3.48 and Makurdi - 2.68 showed that clay soil (Gbajimba has higher conductance than Angbaaye and Makurdi). Therefore, high levels of electrical conductance in these sample shows high level of salts, since it correlates strongly to soil particle size and texture. It is affected and is directly proportional to the pH (number of H^+ ions). It is of high conductivity because it contains minerals in ionic. This is in agreement with a similar reported work (Rodriguez-Perez *et al.,* 2011).

Cation Exchange Capacity (CEC)

This measures the negative charge of solid phase of a soil balanced by exchangeable cations indicated a high percentage of clay and or organic matter which can hold a lot of cations, clays are generally negative due to the presence of layered silicates which derives negative charges. From the results in table 1, (Gbajimba 7.18cmol/kg^{-1}), Angbaaye (7.32cmol/kg^{-1}) and Makurdi (6.98 cmol/kg^{-1}) have a CEC of a little greater than 5 which indicates a high percentage of clay and organic matter. Boul*et al.*, (1980) noted that the CEC range of 3-15cmol/kg^{-1} by NH_4OAC (pH 7) has kaolinite minerals dominant in it. Organic a matter present could be as a result of animal dungs during grazing around the sample site.

Bulk Density

Bulk density reflects the soil's ability to function for structural support, water and solute movement, and soil aeration. High bulk density is an indicator of low soil porosity and soil compaction**.** The result for Gbajimba (1.17g/cm), Angbaaye (0.99) and Makurdi (1.57) indicates the presence of organic matter, especially in Angbaaye which has the lowest result.

Particle Size Distribution (PSD)

From Table 2, using the USDA textural triangle, results revealed that Gbajimba soil sample to be classified as clay having 41.2% clay. Angbaaye and Makurdi were classified as “sand clay loam” having 50.24% and 58.24% of sand, 35.2 and 31.2% of clay and 14.56% and 10.56% respectively. Low clay content as stated by Umeugochukwu, (2009) could also be associated with young age of the soil as an index for measuring soil development. This could also be the type of the parent rock involved in weathering.

SEM Characterization of Clay Samples

Gbajimba- The SEM Micrograph shows high peaks in Silicon and Aluminum while the peaks of other elements are found below. The surface morphology as shown in Figure 3 reveals some level of uniformity in the particle sizes of the Gbajimba soil, but two major class size are observed-.the larger particle size and the smaller particle sizes.

The Energy Dispersive Spectroscopy (EDS) spectrum of Gbajimba sample shows the presence of Silicon having a concentration of 48.72%, Aluminum 15.86% and iron 14.25% Potassium 5.37%, Iodine 3.26%, Titanium 3.06%, Silver 2.59, and Calcium 2.57%. Magnesium 1.17, Phosphorus 1.15, Sulphur 0.85%, Sodium 0.81%, and Manganese 0.35%. Presented in figure 1. Silicon is revealed to have the highest weight concentration and Aluminum and Iron having almost the same level of concentration. This is as a result of the presence of minerals which are dominantly alumino silicates made up of tetrahedron and octahedron sheets constituting a unit cell (Burhan *et al.*, 2010).

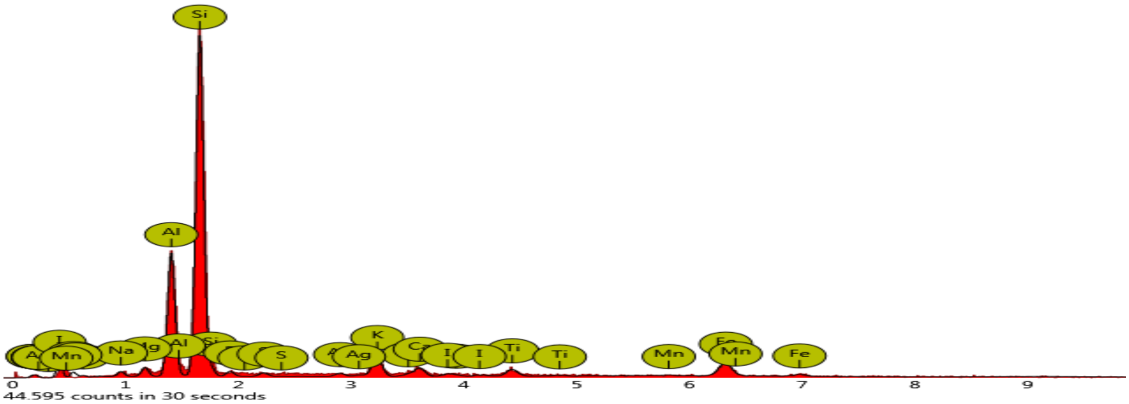

Figure 1: Energy Dispersive X-ray Spectroscopy of Clay-Rich Soils from Gbajimba

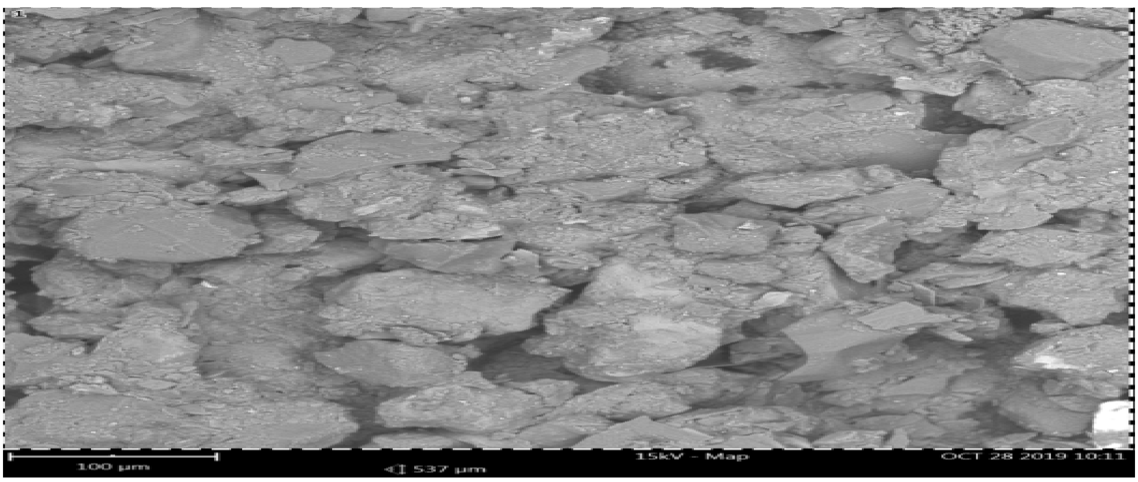

Plate 2: SEM image of Clay-Rich Soils from Gbajimba

Angbaaye - The SEM image in plate 1 shows two different particle size, all of these particles can be grouped into these two sizes- very large particles and very small particle size. From the EDX Spectrum, very high peaks in Silicon ad Aluminum are seen, but unlike the Gbajimba sample, Iron seems to be a bit higher than other elements, after Silicon and Aluminum.

This is also reflected in the weight concentration (EDX) having 35.65% weight of Iron. Silicon shows 36.15 % weight and Aluminum 17.15%, Potassium 4.06%, Titanium 2.25%, Zirconium 1.22%, calcium 0.90%, Magnesium 0.84%, Sulphur 0.47%, Phosphorous 0.45%,Manganese 0.40%, Sodium 0.25% and Vanadium 0.21%.. This implies that the concentration of Iron is higher than Aluminum unlike the Angbaaye sample. Therefore the Angbaaye clay is majorly composed of Silicon and Iron and a slightly high concentration of Aluminum.

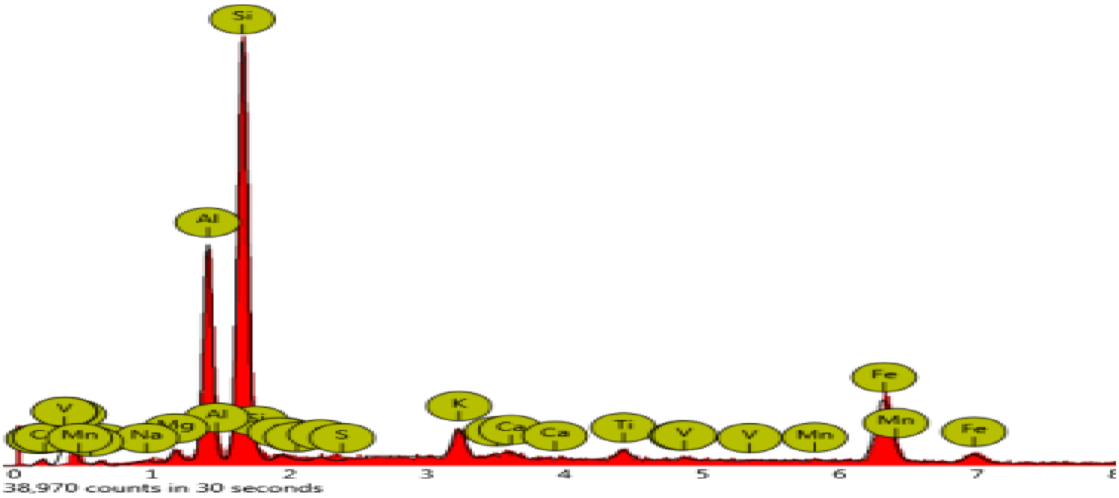

Figure 2: Energy Dispersive X-ray Spectroscopy of Clay-Rich Soils from Angbaaye

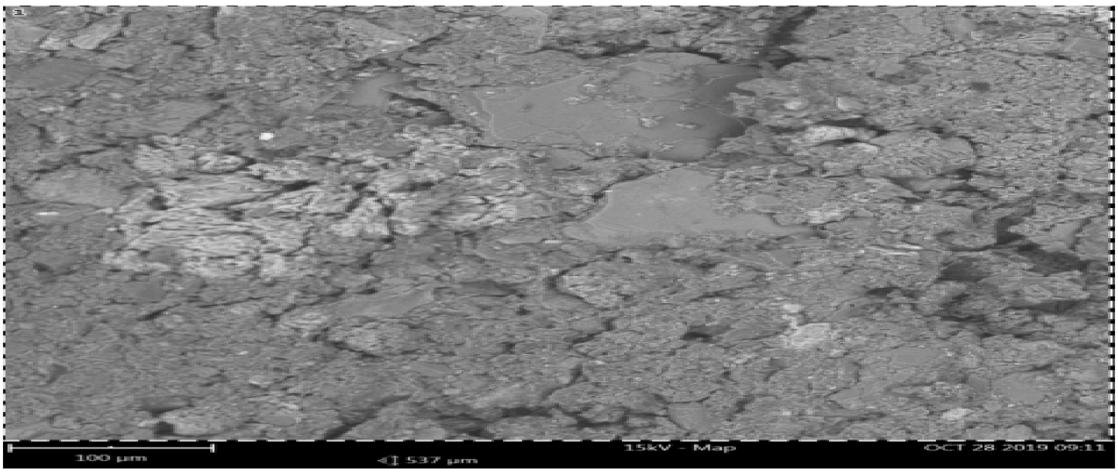

Plate 3: SEM image of Clay-Rich Soils from Angbaaye

Makurdi - The SEM image for the surface morphology shown in figure 8 reveals no uniformity at all in the particle size of the Angbaaye sample; they are all shown to be of varying sizes. The EDS spectrum displayed shows a high peak in Silicon and Aluminum only which is alike when compared with the Angbaaye sample. This is reflected too in the EDS as Silicon and Aluminum seem to be of the highest concentration having a weight concentration of 48.99% and 17.43% respectively. The EDS also reveals weight concentration for other elements such as Iron 17.08%, Potassium 5.40%, Calcium 2.36%, Yttrium 2.19%, Silver 1.87%, Titanium 1.52%, Magnesium 1.35%, Sulphur 0.96%, Phosphorous 0.46%, and Sodium 0.38%.

In the three samples interpreted above, there is an observed trend of Silicon having the highest concentration therefore being the major composition. Aluminum and Iron seem to have an almost equal concentration in all the samples. This is in comparison to Amah's (2011) study on Makurdi clay which revealed SiO_2 concentration to be 42.95, Al (27.38) and Fe (14.95) inferring slight variation especially in the iron and aluminum concentration of the Angbaaye sample.

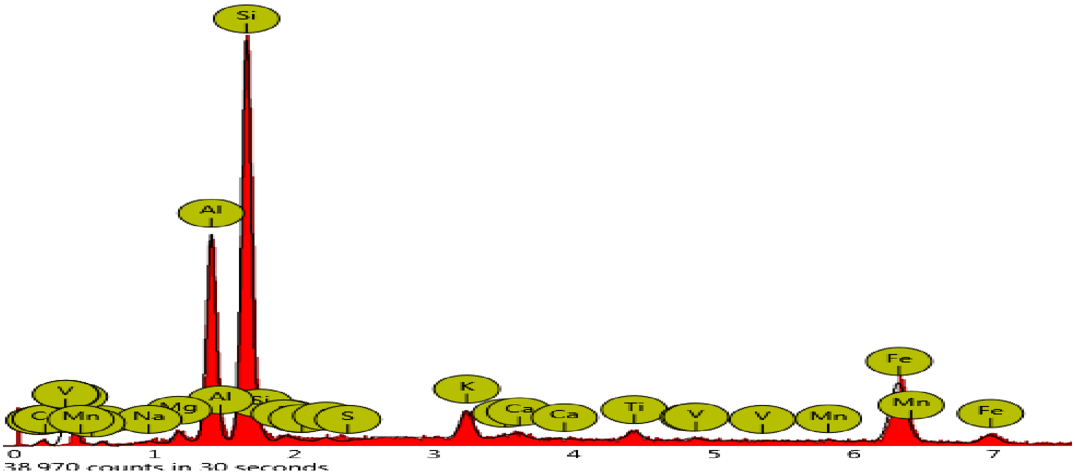

Figure 3: Energy Dispersive X-ray Spectroscopy of Clay-Rich Soils from Makurdi

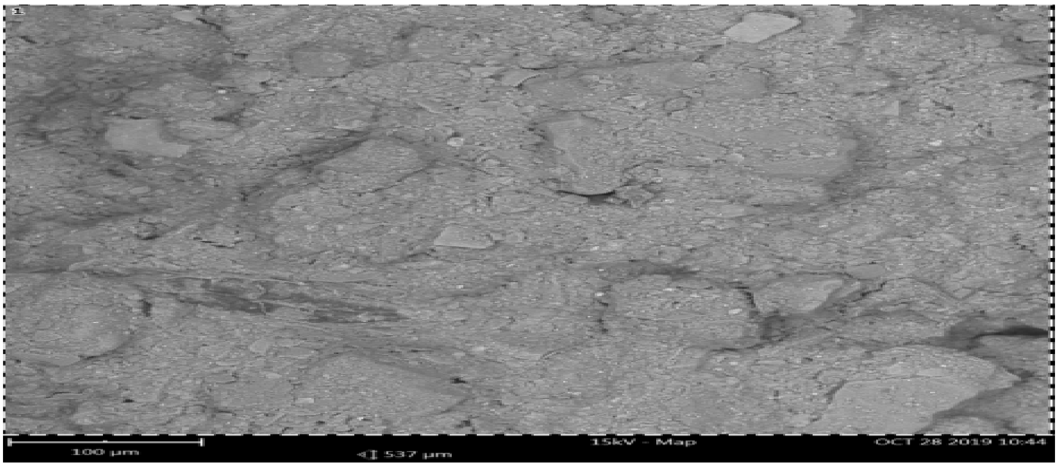

Plate4: SEM image of Clay-Rich Soils from Makurdi

Table 3: **Comparative Chemical Composition of Clay-Rich Soils From Gbajimba, Angbaaye and Makurdi with other Regions**

Major oxide wt (%)	**Gbajimba**	**Angbaaye**	**Makurdi**	**Orin, ekiti**	**Ubiajar**
SiO_2	51.53	49.10	64.82	40.43	55.8
Al_2O_3	18.88	22.41	16.31	29.09	31.62
Fe_2O_3	8.32	8.86	4.26	15.76	3.15
K_2O	0.48	0.44	2.74	0.94	0.25
CaO	0.89	0.52	0.86	0.00	0.09
Y_2O_2	0.003	-	0.003	-	-
TiO_2	1.30	1.36	-	2.01	2.58
MgO	2.10	0.64	1.60	0.94	0.12
SO_2	0.10	0.09	0.06	0.02	-
P_2O_5	0.48	0.44	0.51	0.12	0.42
MnO	0.12	0.18	0.11	0.80	0.10
Na_2O	0.70	0.24	0.85	0.41	0.18
V_2O_5	0.02	0.02	0.01	-	-

Elemental composition based on XRF Analysis

Table 4 presents results of the elemental composition (mg/kg) of Gbajimba, Angbaaye and Makurdi sample. This was done using an X-ray dispersive technique. The results revealed that for heavy metals, iron has a concentration of (25598, 27252, and 13124 mg/kg) respectively, nickel 42, 33 and 18 mg/kg respectively. Copper was shown to have concentration of (34, 23 and 15 mg/kg) respectively. Gallium (55, 61 and 33 mg/kg). Cerium (36, 37 and 23 mg/kg) respectively, Tantalum had a very low concentration of 2 mg/kg for both Gbajimba and Makurdi, but was not detected in Angbaaye. Tungsten had very low concentrations of 8, 9 and 10 mg/kg respectively while Sodium had 48 and 58mg/kg for Gbajimba and Makurdi and a lower concentration of 17mg/kg for Angbaaye. Gbajimba, Angbaaye and Makurdi showed a figure of 466, 365 and 356 for Magnesium. Aluminum showed (14804, 17570 and 12794 mg/kg) respectively, Silicon (50307, 47934, 63278 mg/kg) respectively, this is expected as silicon content is high, an element which is described as the second most abundant element in the earth crust and a major constituent of nearly all rocks (Chukwujike and Igwe, 2016). Potassium was shown to have a concentration of (3265 and 3754 mg/kg) for both Gbajimba and Makurdi but was not detected for Angbaaye. Results shows Calcium having a value of (1844, 1084 and 1775 mg/kg) and Titanium(5482, 5745 and 3952 mg/kg) for Gbajimba, Angbaaye and Makurdi respectively. Vanadium (195, 187 and 122 mg/kg), Chromium (90, 65 and 53 mg/kg), Manganese (1531, 2196 and 1422 mg/kg), Barium (415, 504 and 365 mg/kg) respectively. Arsenic was revealed to have a very low concentration of 2mg/kg in Gbajimba but was not dictated in Angbaaye and Makurdi. Rubidium was (63, 58, and 67mg/kg), Strontium (104, 100, and 135 mg/kg), Yttrium (20, 22, and 17 mg/kg) , Zirconium (251, 325 and 515 mg/kg), Niobium (24, 26, and 18 mg/kg), lead (1, 4, and 5 mg/kg) each element showing its concentration for corresponding Gbajimba, Angbaaye and Makurdi samples respectively. Thorium was not detected in Gbajimba but had a low concentration of 4 and 2 mg/kg in Angbaaye and Makurdi soil samples respectively.

For non-metals phosphorous has a concentration of (885, 816, 937 mg/kg), Sulphur (649, 588, and 387 mg/kg), in Gbajimba, Angbaaye and Makurdi respectively. Chlorine was not deteted at all in Angbaaye and had a low concentration of (7 and 20 mg/kg) in Gbajimba and Makurdi respectively. Bromine had an equivalent of 1mg/kg in all soil samples from the three locations. Titanium and Manganese. Other elements such as Chromium, Vanadium, yttrium, Phosphorous, Barium, Rubidium, lead, sulphur, and chlorine detected are found in very minute/insignificant concentrations.

The XRF results have a relative range of concentration for each element in the sample. The results show three major elements in high concentrations. silicon was the highest concentration in all three samples with maximum concentration in Makurdi (63278 mg/kg). This was followed by the Iron which was a second predominated element in from Angbaaye sample with 27252 mg/kg. The Angbaaye soil samples were of highest Iron and Aluminium content among the samples from the three locations due to the presence of Kaolin ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) and quartz, the products of weathering of K-feldspar rocks (Churchman, 2002). Radionuclides were of low concentration in the samples from two of the locations with none detected in Gbajimba clay samples.

Table 4: Elemental Composition (mg/kg) of Clay-Rich Soils Using XRF

Class		Concentration (mg/kg)		
	Element	**Gbajimba**	**Angbaaye**	**Makurdi**
Heavy metal	Iron	25598	27252	13124
	Nickel	42	33	18
	Copper	34	23	15
	Zinc	208	164	180
	Gallium	55	61	33
	Cerium	36	37	23
	Tantalum	2	ND	2
	Tungsten	10	7	8
	Arsenic	2	ND	ND
	Vanadium	195	187	122
	Titanium	1844	1084	1775
	Chromium	90	65	53
	Manganese	1531	2196	1422
	Barium	415	504	365
Metals	Niobium	63	58	67
Non-metals	Strontium	104	100	135
	Yttrium	20	22	17
	Zirconium	251	325	515
	Lead	1	4	5
	Potassium	3265	3375	3754
	Thorium	ND	4	2
	Sodium	48	17	58
	Magnesium	466	365	356
	Aluminum	14804	17570	12794
	Calcium	3265	ND	3754
	Chlorine	7	ND	20
	Bromine	1	1	1
	Silicon	50307	47934	63278
	Phosphorous	885	816	937
	Sulphur	649	588	387

ND - Not Detected

Mineralogy of Clay-Rich Soils based on XRD Characterization

Six different minerals were shown to be the main minerals in the three samples. These minerals were Quartz, Kaolinite, Microline and Pyrite, muscovite and sylvite. Three of these minerals (quarts, Microline and Pyrite) have their 2ϴ values on the same position. The Gbajimba clay showed the presence of four of these mineral, of which Quartz and Kaolinite are two basic mineral expected in clay used for brick making.

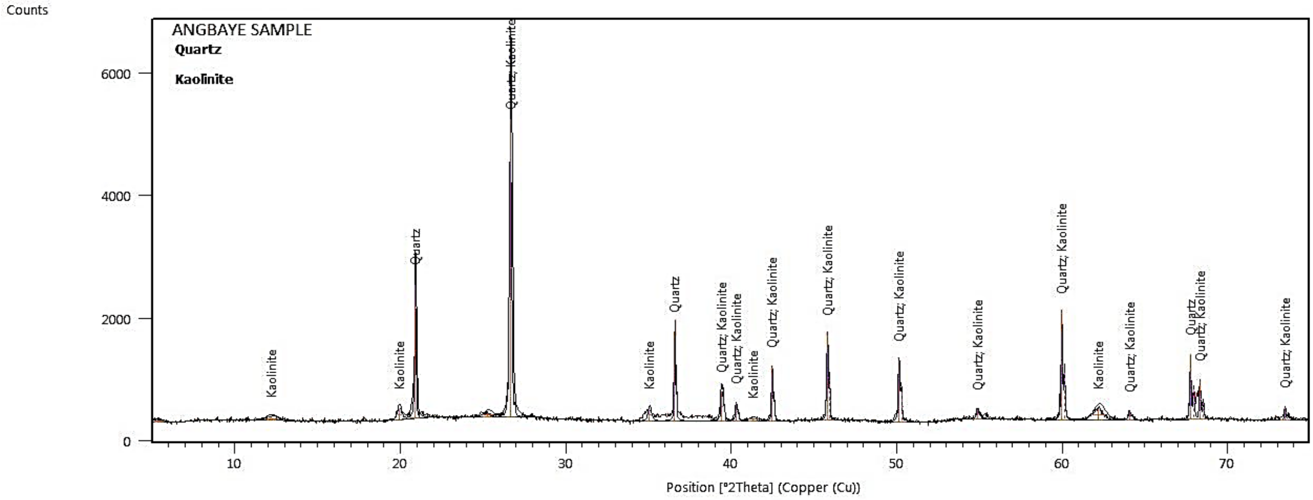

Figure 4: Diffractogram for Angbaaye Clay-Rich Soils

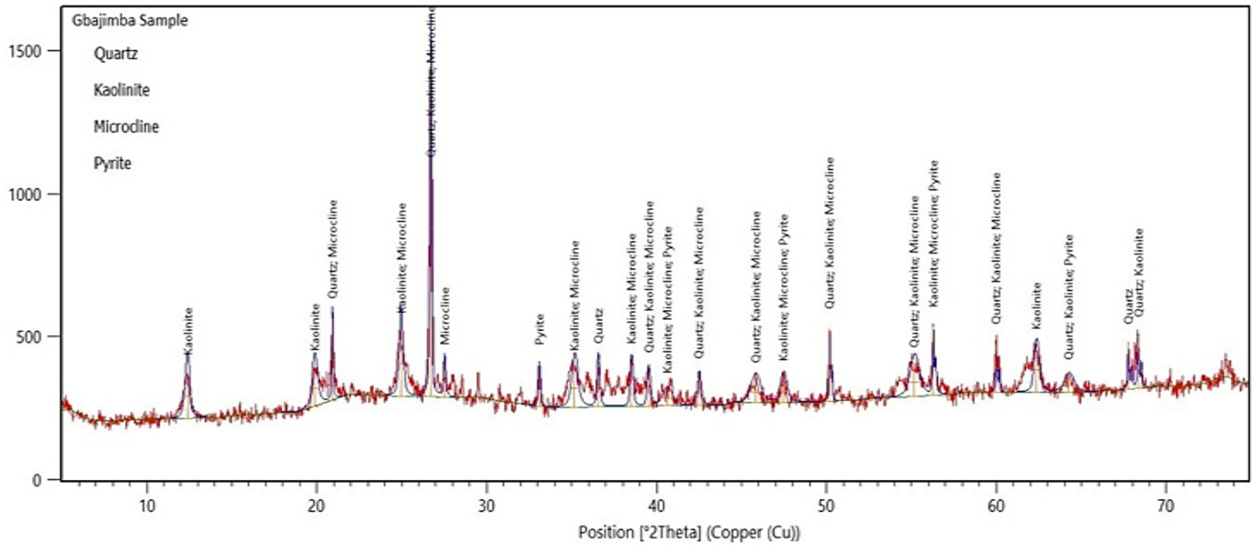

Figure 5: Diffractogram for Gbajimba Clay-Rich Soils

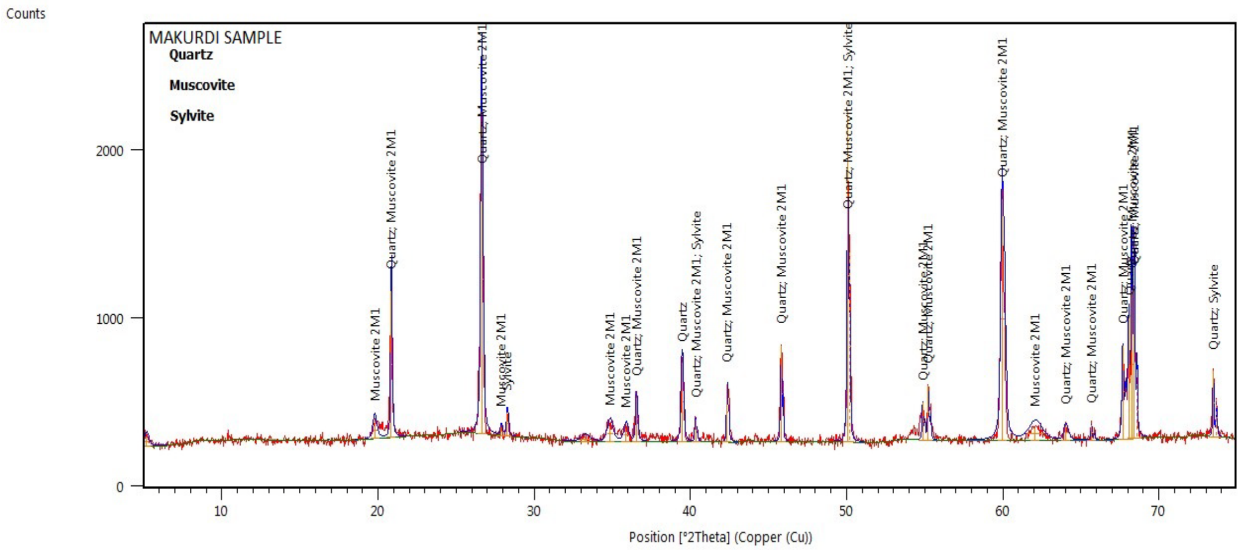

Figure 6: Diffractogram for Makurdi Clay-Rich Soils

Table 5: Associated minerals in Samples from Gbajimba, Angbaaye and Makurdi

S/No.	Associated minerals	Availability		
		Gbajimba	Angbaaye	Makurdi
1.	Quartz	✓	✓	✓
2.	Kaolinite	✓	✓	_
3.	Microline	✓	_	_
4.	Pyrite	✓	_	_
5.	Sylvite	_	_	✓
6.	Muscovite	_	_	✓

Table 6: Crystallographic Parameters of Clay-Rich Soils from Gbajimba

Pos.[2Th.]	FWHMLLEFT [2TH.]	d. spacing [A]	Crystalline size (nm)
12.3842	0.3070	7.14740	9.20164
19.8815	0.3582	4.46585	7.75205
20.9083	0.0763	4.24880	38.29221
24.9500	0.2558	3.56893	11.68402
26.6908	0.1023	3.33998	29.54539
27.5116	0.1535	3.24217	19.801187
33.0852	0.1023	2.70762	31.03951
35.1703	0.4093	2.55173	7.94514
36.5508	0.1535	2.45846	21.37180
38.5099	0.1535	2.33778	21.81358
39.5236	0.1535	2.28013	22.05935
40.6008	0.6140	2.22209	5.58356
42.4876	0.2047	2.12768	17.13669
45.8074	0.6140	1.98091	6.63694
47.4498	0.4093	1.91611	9.17983
50.1792	0.0768	1.81810	51.10643
55.1538	0.6140	1.66531	7.01222
56.2735	0.1023	1.63480	57.39433
59.9714	0.0768	1.54254	62.54719
62.3370	0.3070	1.48957	16.66127
64.2301	0.6140	1.45016	9.78445
67.7651	0.0936	1.38172	64.99836
68.3346	0.1023	1.37272	60.80174
Average Crystalline size		**25.62386**	

Table 7: Crystallographic Parameters of Clay-Rich Soils from Angbaaye

Pos.[2Th.]	FWHMLLEFT [2TH.]	d. spacing [A]	Crystalline size(nm)
5.3847	0.6140	16.41245	4.53521
12.2171	0.8187	7.24481	3.44884
19.9338	0.2558	4.45425	11.36646
20.9149	0.1023	4.24746	28.56093
25.2803	0.6140	3.52304	4.87775
26.6709	0.1535	3.34243	19.6877
35.0492	0.2047	2.56027	14.2136
36.5751	0.0768	2.45689	42.7263
39.4134	0.1791	2.28625	33.3943
40.2985	0.1023	2.23806	18.8828
41.2952	0.6140	2.18632	5.62985
42.4710	0.0768	2.12847	39.6509
45.8104	0.0936	1.97915	39.1527
45.9529	0.0624	1.97824	12.8945
50.1385	0.1248	1.81797	31.40247
50.2959	0.0624	1.81716	63.12868
54.8872	0.1560	1.67138	27.4269
59.9811	0.0936	1.54104	51.2909
60.1605	0.0936	1.54069	51.64892
62.2099	0.7488	1.49107	6.80108
64.0622	0.1248	1.45235	43.06693
67.7594	0.0936	1.38182	64.98461
67.9528	0.0936	1.38179	70.36304
67.3381	0.0936	1.37153	65.12732
68.5324	0.0936	1.37151	67.06852
73.4830	0.0936	1.28768	83.50775
Average Crystalline size			**34.80149**

Table 8: Crystallographic Parameters of Clay-Rich Soils from Angbaaye

Pos.[2Th.]	FWHMLLEFT [2TH.]	d. spacing [A]	Crystalline size (nm)
5.1808	0.3070	17.05765	9.06803
19.7872	0.3070	4.48692	9.46470
20.8501	0.1023	4.26052	28.55162
26.6292	0.1535	3.34756	19.68236
27.8922	0.1279	3.19879	23.92903
28.2748	0.1279	3.15637	23.89313
33.2297	0.6140	2.69618	5.68829
34.8408	0.4093	2.57511	7.88283
35.8609	0.3070	2.50416	10.61300
36.5367	0.1279	2.45938	25.64591
39.4550	0.1535	2.28394	24.49151
40.3281	0.1023	2.23649	33.48732
42.3571	0.1023	2.13393	34.22727
45.8015	0.0768	1.98115	47.75081
50.0646	0.0936	1.82048	41.81803
50.2141	0.0624	1.81992	63.07374
54.8666	0.0936	1.67196	45.69255
55.2315	0.0936	1.66178	46.03452
59.0438	0.2184	1.54170	21.18352
62.0438	0.9984	1.49466	5.07735
64.0041	0.2496	1.45353	21.49557
65.6890	0.0936	1.42027	60.46038
67.6784	0.1248	1.38328	48.59375
68.0573	0.1248	1.37650	49.28064
68.2457	0.0936	1.37316	6.61750
68.3995	0.0936	1.37044	66. 56246
68.6062	0.0936	1.37022	67.25967
73.4771	0.0936	1.28777	83.48069
73.6913	0.0936	1.28775	84.64001
Average Crystalline size		**35.02223**	

Fourier Transform Infra-red Spectroscopy of Clay-Rich Soil Samples

The observed absorption at 3693.8 and 3623.0 could be credited to O-H stretching. This is in line with El Kasim *et al.* (2016) findings which shows the OH stretching vibration band that manifests at 3698.1 cm^{-1}, 3622.6 cm^{-1}, 3411.7 cm^{-1}, 1638.9 cm^{-1}, 1032.2 cm^{-1}, 914.3 cm^{-1} and 799.2 cm^{-1}, 775.3cm-1 indicated the presence of kaolinite. The absorptions observed at 3526.1-3444.1 cm^{-1} in Angbaaye, 3597.5-3623.0cm^{-1} in Makurdi, are due to O-H stretching that could arise from Si-OH or H-O-H stretching. Frequency at 1628.8 cm^{-1} in Angbaaye is a characteristic of C-O bending (Shokri *et al.*, 2009). The vibration at 2109.7cm^{-1} in Angbaaye and 2068.7cm^{-1} in Makurdi is typical of Si-C stretching. The peaks at 678.4 in Angbaaye, can be assigned to the Al-O stretching mode in octahedral structure; while band around 745.5 cm^{-1} is related to Al-O stretching mode in tetrahedron (Djebaili *et al.*, 2015). In Makurdi clay, two peaks are observed at 1002.7 $cm^{-1}$and 1047.4cm^{-1}(Gbajimba and Makurdi) having a resemblance of that of Si-O-Si stretching (Shokri *et al.*, 2009) by XRF analysis. Significant amount of Fe_2O_3 was also detected by XRF experiment.). This is also in line when compared with El Kasim *et al*. (2016) indicating the Si–O stretching bands at 1095 cm^{-1} and the Al–O bending at 912 cm^{-1} are characteristic of alumino-silicate minerals. The major composition of samples at Gbajimba, Angbaaye and Makurdi are showed to be Al_2O_3 and SiO_2. This is confirmed in the percentage weight chemical composition in XRF.

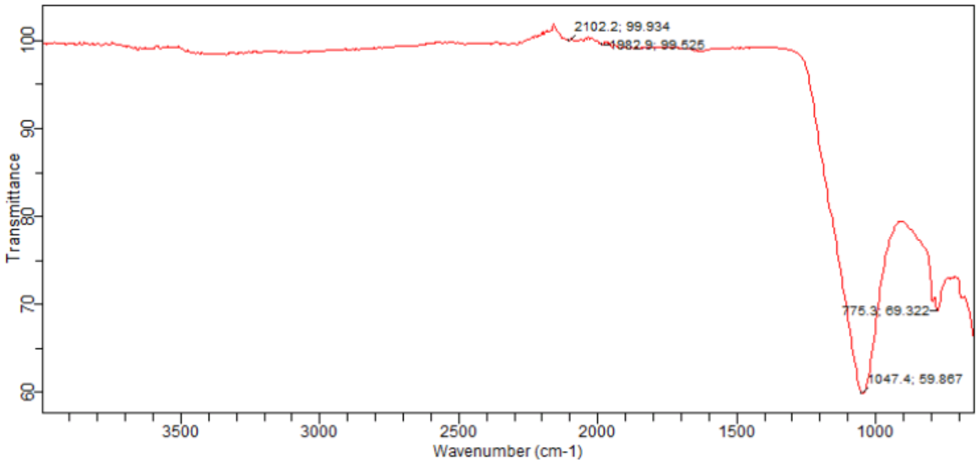

Figure 7: Fourier Transform Infra-red Spectrum of Clay-Rich Soil from Gbajimba

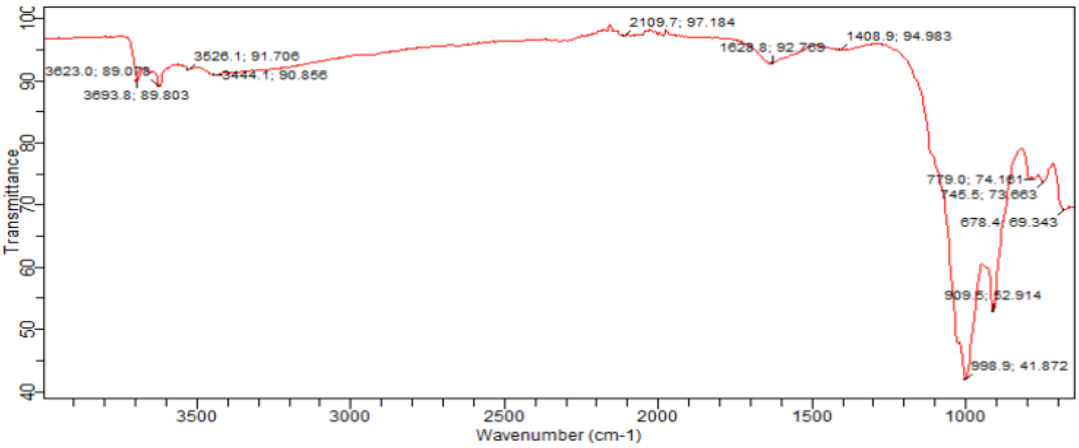

Figure 8: Fourier Transform Infra-red Spectrum of Clay-Rich Soil from Angbaaye

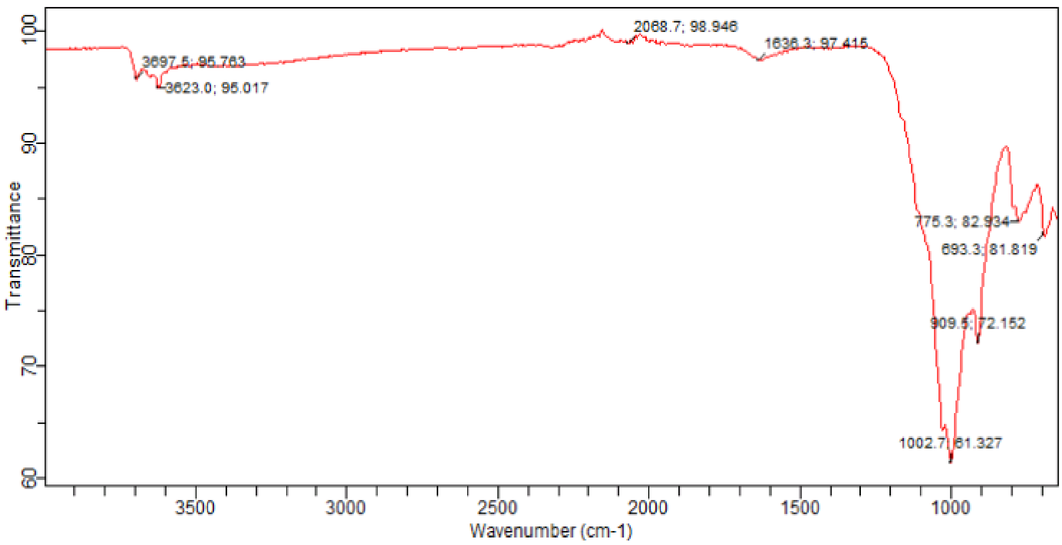

Figure 9: Fourier Transform Infra-red Spectrum of Clay-Rich Soils from Makurdi

CONCLUSION

Clay- rich soil samples from Angbaaye, Gbajimba and Makurdi areas of Benue state were successfully characterized for their chemical and mineralogical contents. All three samples shows varying levels of associated minerals (Quartz, Kaolinite, Microline and Pyrite, muscovite and sylvite) and chemical compositions, with Gbajimgba soil having more clay contents.

Conflicts of Interest

There is no conflict of interest regarding this publication of this article**.**

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